Using NOGAPS Singular Vectors to Diagnose Large-scale Influences on Tropical Cyclogenesis

PI: Prof. Sharanya J. Majumdar
RSMAS/MPO, University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149.
Phone: (305) 421 4779 Fax: (305) 421 4696 Email: smajumdar@rsmas.miami.edu

Co-PIs: Dr Melinda S. Peng, Dr Carolyn A. Reynolds, Dr. James D. Doyle
Naval Research Laboratory
7 Grace Hopper Avenue
Monterey, CA 93943.
Peng: Phone: (831) 656 4704. Email: melinda.peng@nrlmry.navy.mil
Reynolds: Phone: (831) 656 4728. Email: carolyn.reynolds@nrlmry.navy.mil
Doyle: Phone: (831) 656 4716. Email: james.doyle@nrlmry.navy.mil

Co-PI: Prof. Chun-Chieh Wu
Dept of Atmospheric Sciences
National Taiwan University, No. 1, Sec. 4
Roosevelt Rd, Taipei 10673, Taiwan.
Phone: +886-2-2363-2303. Email: cwu@typhoon.as.ntu.edu.tw

Co-PI: Prof. David S. Nolan
RSMAS/MPO, University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149.
Phone: (305) 421 4930 Fax: (305) 421 4696 Email: dnolan@rsmas.miami.edu

Grant Number: N000140810250
http://www.rsmas.miami.edu/personal/myamaguchi/

LONG-TERM GOALS

The overarching goal is to improved our understanding of synoptic-scale influences on tropical cyclone (TC) formation and motion in the western North Pacific Ocean, in the context of error growth in forecast models. Benefits to the Navy would include improved forecast skill of the structure and track of developing and recurving TCs.

OBJECTIVES

One objective is to connect NOGAPS Singular Vector and ensemble perturbation growth to synoptic-scale dynamical influences on tropical cyclone formation and structure change. This objective is coupled with an evaluation of the influence of assimilating TCS-08 and T-PARC observations into the

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2009		**00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Using NOGAPS Singular Vectors To Diagnose Large-scale Influences On Tropical Cyclogenesis	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Miami,RSMAS/MPO,4600 Rickenbacker Causeway,Miami,FL,33149**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The overarching goal is to improved our understanding of synoptic-scale influences on tropical cyclone (TC) formation and motion in the western North Pacific Ocean, in the context of error growth in forecast models. Benefits to the Navy would include improved forecast skill of the structure and track of developing and recurving TCs.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**6**	

Navy global assimilation and forecast system. Another objective is to extend these investigations towards vortex initialization and analysis of tropical cyclone *structure change* in high-resolution models. The goal is to extend these methodologies into the Navy's developing COAMPS-TC framework.

APPROACH

The dominant sensitivity patterns, evolving horizontal and vertical structure and error growth associated with the NOGAPS SVs are being investigated for the TCS-08 cases, from the formation stage through to typhoon status. The connection between these perturbation structures and synoptic-scale processes influencing developing tropical cyclones will be explored, expanding upon the case study of Yamaguchi et al. (2008). In addition to the regular dry SVs, moist SVs will be analyzed for interesting cases. Prior to this investigation, hypotheses for SV perturbation growth are presently being formulated by Munehiko Yamaguchi, the graduate student funded on this grant, using a barotropic model and singular vectors based on Nolan and Farrell (1999). Concurrently, the effectiveness of assimilating TCS-08 observations on NOGAPS predictions of tropical cyclone track and structure is being evaluated at NRL, via "data denial" in the Navy global model framework. The modification to the NOGAPS synoptic fields due to the special observations will be analyzed and compared with the SV structures, elucidating the effectiveness of the SV structures in accounting for perturbation growth.

New vortex initialization methods that are based on theory and observations are designed to provide superior representations of initial TC structure in high-resolution models than are presently achievable via data assimilation. The 2-km resolution version of the Weather Research and Forecasting (WRF) model is presently being used for this purpose, and the initialization code will be portable to the COAMPS-TC framework at any time. Research on the sensitivity of numerical simulations to different prescriptions of the initial vortex is under way (results below).

Ensemble-based sensitivities and predictability studies also being conducted in parallel, and two papers are under review (results below). The approach is to investigate perturbations and error growth from ensembles in the THORPEX Interactive Grand Global Ensemble (TIGGE), for cases pertaining to TCS-08. The results have been communicated via seminars and conference calls with the Co-PIs at NRL Monterey, and offer a comparison method for the new NOGAPS ensemble being developed at NRL.

WORK COMPLETED

NOGAPS SV guidance for adaptive observations was provided by NRL in real-time during the TCS-08 field phase, for TC formation and recurvature (Fig. 1). This is the first time that SVs have been applied for use in TC formation. Since TCS-08, hypotheses pertaining to the effectiveness of evolving SVs in capturing TC forecast errors have been formulated. They are first being examined in a barotropic model framework, and those successful hypotheses will be extended to the NOGAPS SVs such as those in Fig. 1.

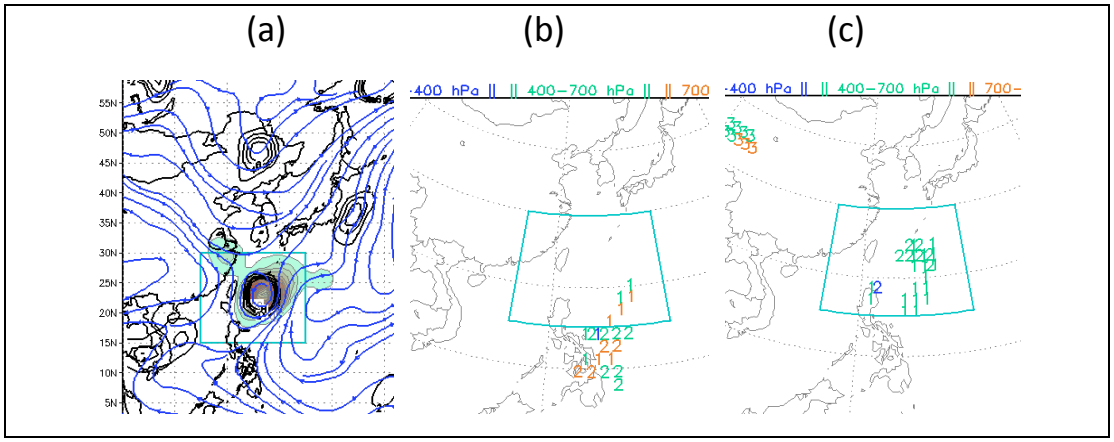

FIGURE 1. NOGAPS SV sensitivity guidance for system TCS033, which developed into Typhoon Sinlaku. (a) integrated total energy of the leading 3 initial-time SVs; (b) sensitivity to vorticity in each of the first 3 SVs (denoted by number on map); (c) corresponding sensitivity to temperature.

The improvements to TC structure in the high-resolution WRF model due to the insertion of a synthetic vortex in gradient wind balance are shown in Fig. 2. The synthetic vortex uses TCS-08 observations to define its basic structure. The associated forecast of Sinlaku (not shown) maintains a more realistic structure than if WRF initialized off a global model with no synthetic vortex were used.

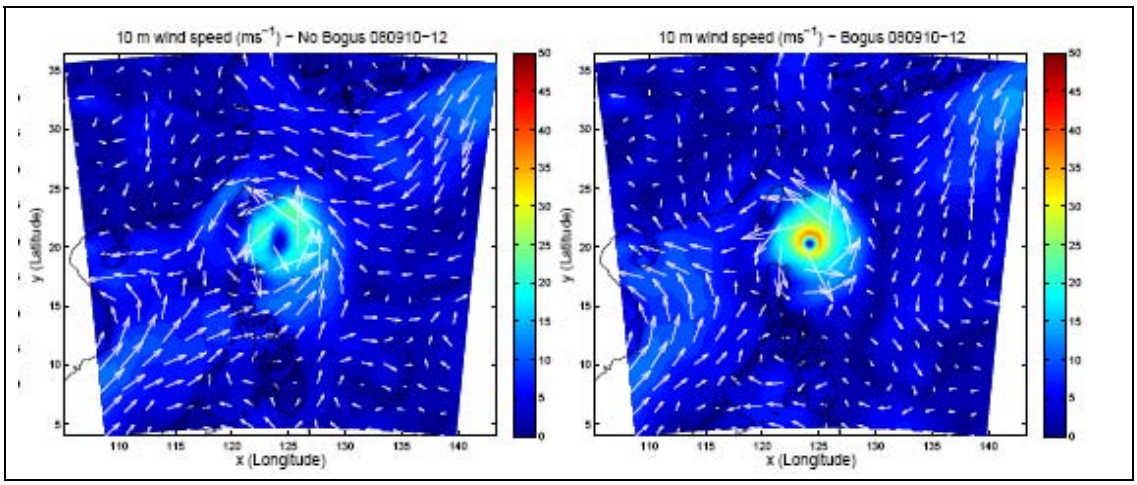

FIGURE 2. Left: WRF initial condition of Typhoon Sinlaku with no synthetic vortex added. Right: corresponding initial condition with synthetic vortex.

Evaluations of the ECMWF ensemble mean and track probabilities have been completed for the 2008 western North Pacific season, and compared against the Navy's current consensus model (CONW) and associated Goerss Predicted Consensus Error (GPCE) track probability circles (Figure 3). It was found that the ECMWF ensemble mean was significantly superior to CONW (Fig. 3a), resulting in a slightly better estimation of the 67% probability 'cone of uncertainty' than that constructed using GPCE, for forecasts beyond 2 days (Fig. 3b). The widths of the ensemble-based cones of uncertainty are on

average smaller than the GPCE-based cones (not shown). This study has resulted in a paper (Majumdar and Finocchio 2009), and discussions are ongoing with NRL personnel.

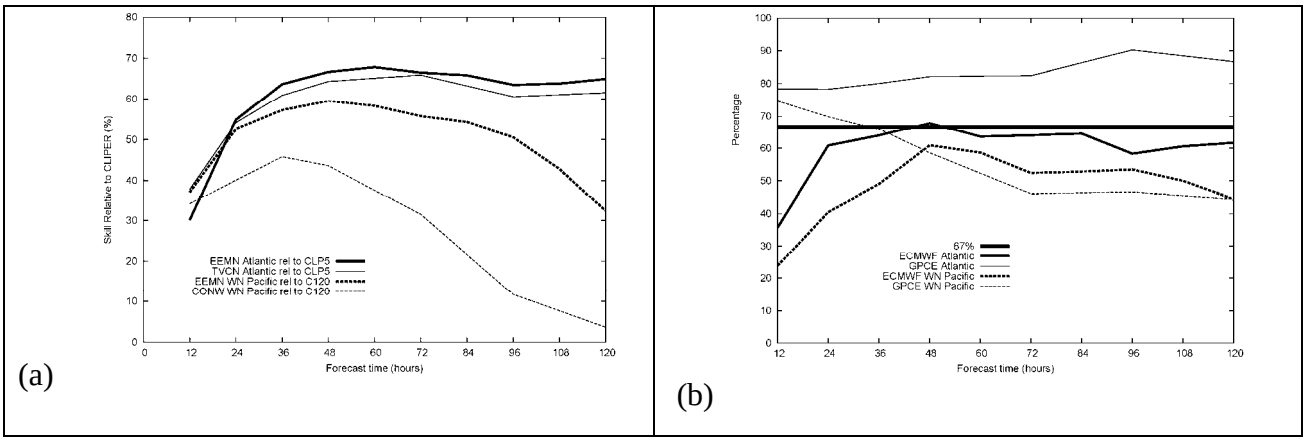

FIGURE 3. (a) TC track forecast errors (in km) of ECMWF ensemble mean, operational consensus and CLIPER forecasts in the western North Pacific and Atlantic basins. (b) Percentage of cases in which the ECMWF 67% probability circles and the corresponding 67% GPCE circles contained the best track. 138 cases (Western N. Pacific) and 165 cases (Atlantic) were used.

Finally, an examination of TIGGE ensemble perturbation structure in the environment of Typhoon Sinlaku has been performed. It was found that the vertical structure of perturbations around the TC differed considerably between ensembles from different operational centers (Fig. 4a). The horizontal distribution of initial ensemble perturbations was also different between the various centers; for example, the ECMWF perturbations that are conditioned to grow rapidly over a 48-hour period were most prominent in the subtropical ridge to the east of the intensifying Sinlaku (Fig. 4b). The ECMWF ensemble was found to produce faster growing ensemble perturbations (and therefore a broader, more realistic spread in TC tracks) than other ensembles, as is evident if Fig. 4c. A paper on this work is under review (Yamaguchi and Majumdar 2009), and Munehiko Yamaguchi presented these results at a seminar at NRL Monterey in September 2009.

RESULTS

Several conclusions have been derived so far. First, the NOGAPS SV sensitivity is found to lie usually on (i) the eastern and southern side of the cyclone, corresponding to the periphery of the subtropical ridge influencing the cyclone's motion and wind field, and (ii) to the north and north-west, associated with the interaction with an approaching shortwave trough. These results are consistent with those found in earlier studies by Co-PIs Peng and Reynolds. However, for formation, which is the primary and most novel focus of this project, the cases need to be investigated in more detail since the sensitivity appears less intuitive on first inspection.

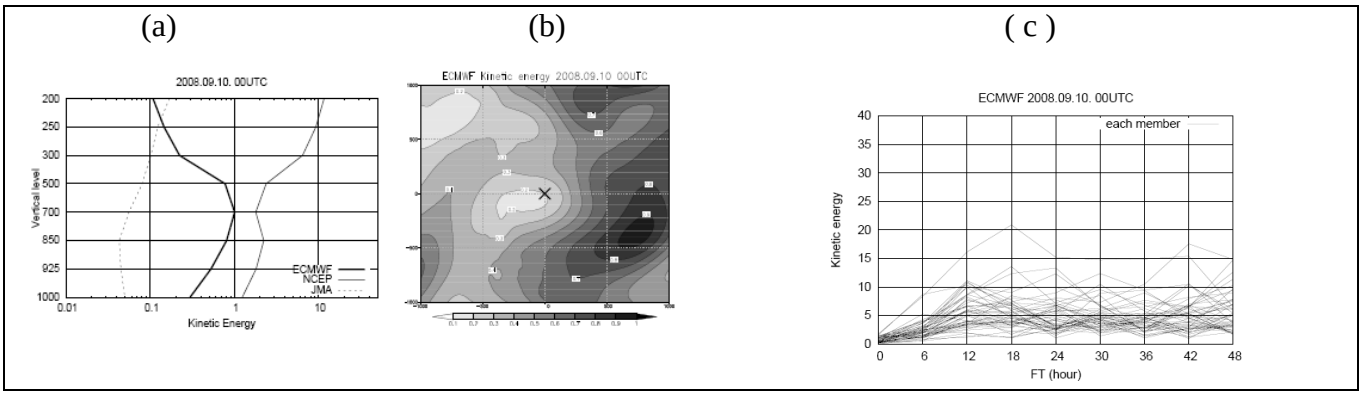

FIGURE 4. (a) Vertical distributions of 'perturbation kinetic energy' of the ECMWF, NCEP and JMA ensembles, averaged over a 2000 x 2000 km domain centered on Typhoon Sinlaku. (b) Corresponding horizontal distribution for the ECMWF ensemble. (c) ECMWF ensemble perturbation growth in the 2000 x 2000 km domain out to 48 hours. All ensemble forecasts are initialized at 00 UTC, 10th September 2008. The symmetric component of the vortex has been removed in each ensemble member to isolate the environmental flow and asymmetries in the TC.

Second, an initial synthetic vortex is necessary in order to capture the realistic structure in high-resolution models. In the absence of a mesoscale data assimilation scheme, a high-resolution model nested within a global model (such as NOGAPS) produces either slow TC formation and development, or no development at all. The TCS-08 observations are being used in the construction of the synthetic vortex, and asymmetric components of the TC and the secondary circulation will also be constructed within the next year.

Third, the ECMWF ensemble provides potential for improvement of consensus and probabilistic track forecasts of TCs in the western North Pacific basin. And finally, the ECMWF ensemble was found to comprise perturbations in the mid-troposphere near the TC, and its perturbation growth was more rapid than other ensembles over two days.

IMPACT/APPLICATIONS

The scientific impact will be an improved understanding of the underlying environmental mechanisms that influence tropical cyclone formation. This understanding will be coupled with a quantitative knowledge of error growth in global models, via SVs and ensembles. The SVs also possess practical value in that they can be used in future targeting applications. High-resolution simulations and vortex initialization will be performed in collaboration with the COAMPS-TC developers at NRL Monterey, leading to improved Navy forecasts of TC structure. Finally, the global ensemble results will assist in the development of the new NOGAPS ensemble, and Navy consensus mean and probabilistic predictions may be improved via the use of global model ensembles.

RELATED PROJECTS

This project is related to that funded by the TCS-08 grant N000140810251: "Advanced Satellite-Derived Wind Observations, Assimilation, and Targeting Strategies during TCS-08 for Developing

Improved Operational Analysis and Prediction of Western North Pacific Tropical Cyclones", on which Majumdar is a Co-PI. The NOGAPS Singular Vectors are also investigated in this grant. The high-resolution modeling and vortex initialization tools developed as part of this project will be used in the new collaborative NOPP grant between the PI and CIMSS Wisconsin, NRL Monterey and NCAR, on assimilating satellite data to improve forecasts of TC intensity change.

PUBLICATIONS

Majumdar, S. J. and P. M. Finocchio, 2009: On the ability of global Ensemble Prediction Systems to predict tropical cyclone track probabilities. *Wea. Forecasting*, accepted subject to major revisions.

Yamaguchi, M. and S. J. Majumdar, 2009: Using TIGGE data to diagnose initial perturbations and their growth for tropical cyclone ensemble forecasts. *Mon. Wea. Rev.*, Under Review.

Yamaguchi, M., T. Iriguchi, T. Nakazawa, and C.C. Wu, 2009: An Observing System Experiment for Typhoon Conson (2004) Using a Singular Vector Method and DOTSTAR Data. *Mon. Wea. Rev.*, **137**, 2801–2816.

Yamaguchi, M., R. Sakai, M. Kyoda, T. Komori, and T. Kadowaki, 2009: Typhoon Ensemble Prediction System Developed at the Japan Meteorological Agency. *Mon. Wea. Rev.*, **137**, 2592–2604.